Rick Lawrence

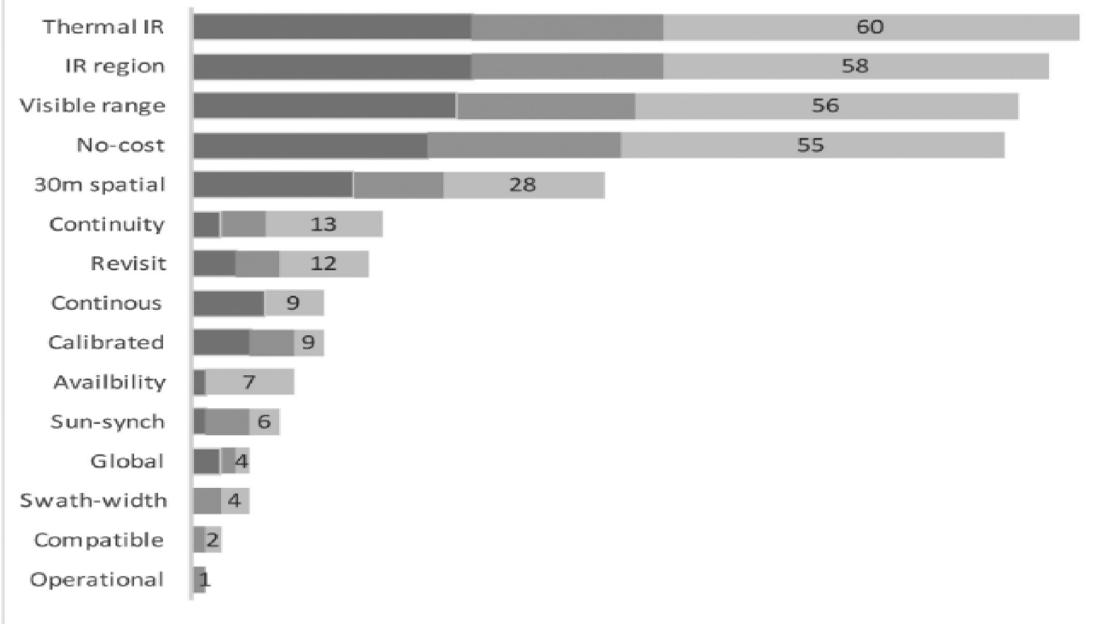


Figure 2. Characteristics of Landsat program or data recommended by the AmericaView community that should be retained in future Landsat missions.

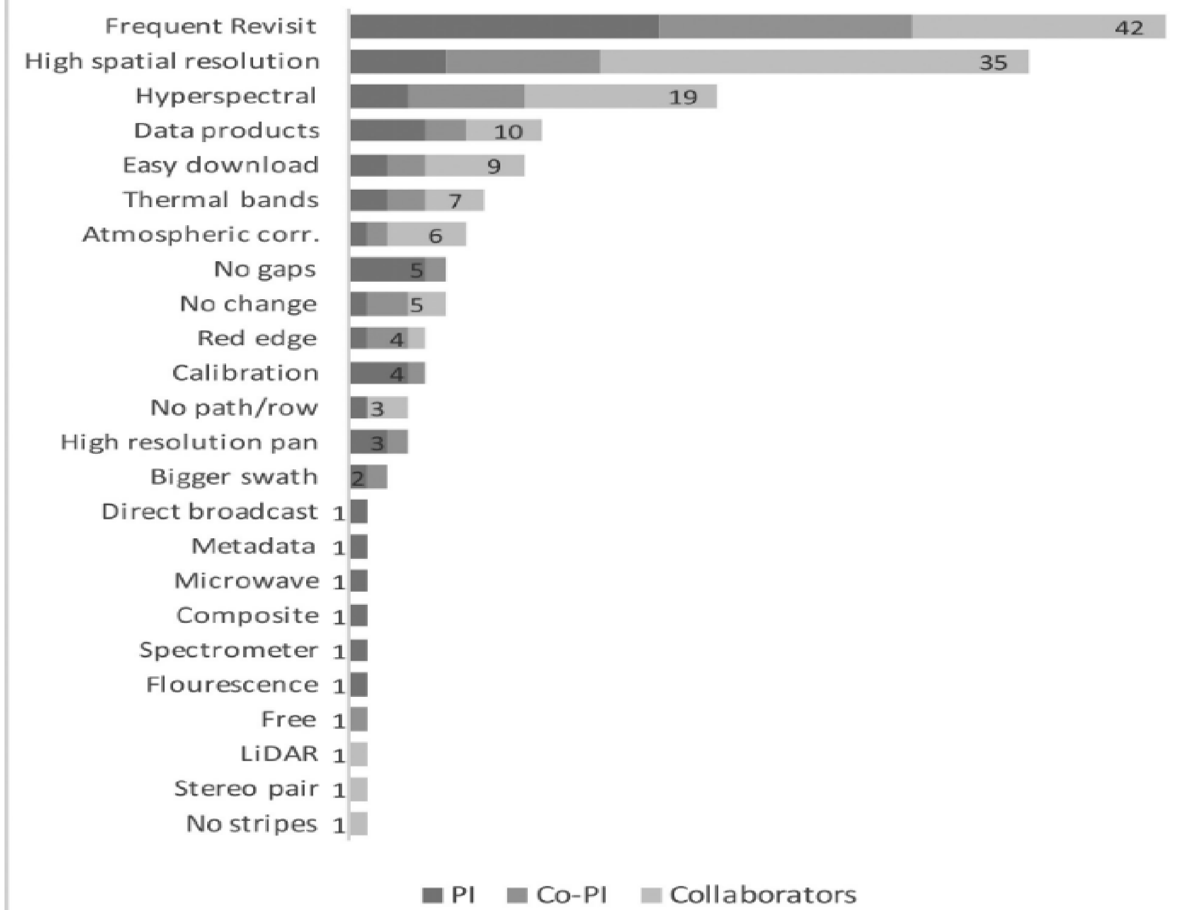


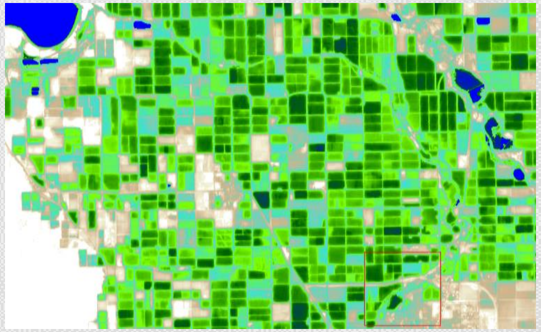
Figure 3. Recommendations made by the AmericaView community in terms of changes that could be made to future missions that would further increase the use of Landsat data.

AMERICA VIEW

Future Landsat data needs at the local and state levels: an AmericaView perspective, Sivanpillai and Congalton, *PE&RS,* In Press.

Richard Allen, Univ. Idaho, Member, LST

Specialist in Evapotranspiration Mapping



Imperial Valley, CA

Short wave:

- 30 m pixel size or smaller
- Blue, Green – needed for broadband albedo
- Red, NIR – needed for vegetation indices, vegetation amount
- SWIR (two bands: ~1.55-1.7 and ~2.1-2.3) – for broadband albedo and organic residue

Thermal:

- 60 m pixel size or smaller for distinguishing actual ET on a field-by-field basis for water rights management, hydrology, court actions, water management
- Two bands: ~10.6-11.19 and ~11.5-12.51 for split window retrieval of surface temperature and conduct of a surface energy balance
- Coincident with short wave (within 20 seconds) for cloud identification

Satellite Attributes:

- 30 degree field of view for a ~300 km swath width
- 16 day or shorter revisit per satellite
- Two Landsat 10 satellites (10a and 10b) for an effective 4 day revisit (with 30° FOV) to mitigate for cloud cover in regions having moderate to persistent clouds

Desired capabilities for Landsat 10 (agricultural perspective)

Anderson/Gao/Daughtry USDA

Bands:

- Two or more thermal bands (multi-bands enable temperature-emissivity separation)
- VNIR spectral bands at least meeting current Landsat standard (prefer Landsat 8 NIR)
- Cirrus band for cloud detection
- Red edge band
- Tillage index bands used for residue mapping

Wavelengths, nm	Residue index
2025-2035 2095-2105 2200-2210	Cellulose absorption index (CAI)
2185-2225 2235-2285	Shortwave Infrared Normalized Difference Residue Index (SINDRI)
1550-1750 2080-2350	Normalized Difference Tillage Index (NDTI)

Spatial Resolution:

- Minimum – match Landsat 7
- More optimal, TIR at 30m, shortwave at 10m

Temporal Resolution:

- Improve temporal frequency with multiple clones of L10 or wider swath
- Minimum – weekly revisit
- More optimal, 2-4 day visit

Other considerations:

L10 orbit may match one of operational coarse resolution sensors like VIIRS to enhance data fusion capabilities (encourage morning VIIRS)

Cohen

Essential capabilities for L10 era data – Cohen (USFS)

- ARD or better geometry

- 30m resolution, near daily observations to achieve clear view density in cloudy places that increases likelihood phenology is detectable

- S/N quality and radiometric integrity at least as good as L8, with pre-planned, built-in harmonization of time series (at least in terms of common spectral indices) – maybe fix the band passes at this time?

- Specs that coordinate with Sentinel and related data acquisitions to ensure integration success in temporal, spatial, and spectral domains

- Delivery of free data in a timely manner (immediately?)

- Delivery of vetted global land cover and change products

Helder

Landsat 10 Input

From a calibration perspective it's all about radiometric, spatial, temporal, and spectral resolution…

- **Radiometric**: current 12→14 bit resolution for Landsat 8/9 seems adequate for applications and at the edge of system design and stability capabilities. OLI SNR is a key factor; suggest we maintain it.
- **Spatial**: Current 30/15m capability adequate. Does the science community foresee a 15/10m future? Primarily driven by data throughput and volume.
- **Temporal**: Currently significant limiting factor. Suspect 4 day repeat coverage necessary for ag. Are we really headed to daily coverage?
- **Spectral**: This is the key issue—can we standardize spectral bandpasses? Single biggest issue in data continuity going backward. OLI's are great! Or are we headed towards hyperspectral?

Hipple

USDA RMA Landsat 10+

- Essential capabilities for applications work:
  - consistency is probably the most important aspect for our applications needs
  - spectral band desires (current with room for improvements):
    - 10-m RED & NIR for a 10-m NDVI
    - New bands:
      - Red edge – similar to Sentinel 2
      - Cellulose – 2040 (2025–2055); 2100 (2080–2120); 2210 (2190–2230)
  - increased acquisition frequency
    - increased swath width or multiple satellites
  - ease of access / delivery mechanism
    - deliver full resolution data sets but with limited band combinations (selectable by user or template driven)
    - subscribe-able derived LST products

Hostert

Landsat 10 essential capabilities (ordered by importance)

1. Backwards compatibility with L8/9 and S2 a/b/c/d
2. Improved temporal resolution (constellation/swath?)
3. Improved spatial resolution e.g. supporting analyses of urban environments. Spatial resolution is ideally the same from VIS to SWIR.
4. Additional narrow bands, e.g. for improved vegetation analyses (red edge, chlorophyll fluorescence, quenching)

Beyond the sensor and maybe earlier than L10:

- Scientific processing capacities „close to the data"
- free VHR samples for cal/val of higher level LCLUC products

Johnson

USDA Crop Production Monitoring Needs for Landsat 10

Crop identification/area:

Finer spatial resolution

- This is particularly needed in regions with fields that are less homogeneous or smaller in size.
- 10 meter (15 meter would also be considered a significant improvement, 5 meter would also be entertained).

Shorter revisit rate

- Currently 16-day revisit cycles does not guarantee a cloud-free observation over a growing season in humid regions.
- 8 day would be minimum.

Crop progress/condition/yield:

Much shorter revisit rate

- Would really like to capture weekly status of crops.
- 4 day minimum (2 or 1 day probably truly needed however).

Thermal/surface temperature data

- Has shown to be helpful in the MODIS context in terms of the relationship to yield.

Unknowns:

- Thermal data: Still not clear the full utility of temperature data for crop production monitoring. The coarser resolution, compared to the multispectral, has been a hindrance to fully test/accept.
- Red-edge band(s): Has held promise for improved vegetation mapping but not really explored and documented to date. Sentinel-2 is now finally providing a true test platform.
- Overpass times and viewing geometry angles are of secondary concern (versus getting no data).

Kennedy

Landsat 10 continuity

- Tie-back to existing time-series, but also to other sensors
  - Break L5/L7-style wide NIR into a few smaller chunks that could be more easily linked with L8+9, L5+L7 (by combination), or other sensors? Perhaps same with SWIR (if SNR allows).
- Improved in-sensor bands for atmospheric and cloud handling
  - Maintain cirrus, but also include narrow bands (water vapor features, etc.) that would make these tasks much easier in standalone mode
- Get thermal back on board
- Consider constellation or some means to get repeat time down to 3-5 days – without relying on Sentinel.
- Don't kill the messenger:
  - The single most-requested thing I hear from remote sensing folks outside the Landsat community is "if Landsat were just closer to hyperspectral, we could create any bands we needed." Just sayin'.

Ayse Kilic, Univ. Nebraska-Lincoln, Member LST
Spatial Evapotranspiration from Agriculture and Natural Systems

Landsat 10 Requirements:

- 8 day revisit via wider swath (30° field of view) and/or multiple platforms
- Short wave bands (for surface albedo, vegetation indices, aerodynamic roughness, soil heat flux, organic residue):
  - Spatial resolution of 30 m or smaller, consistent with Landsats 5, 7, 8, 9
  - Continuity with and similar placement of bands as Landsats 5, 7, 8, 9
  - Hyperspectral short wave imager should be encouraged, with ability for red edge and improved vegetation identification, and with combination of narrow bands to produce legacy Landsat bands, provided the signal-to-noise ratio can be maintained at those of Landsats 8 and 9.
- Thermal: two bands similar to Landsats 8 and 9 for split window-based atmospheric correction
  - Prefer 60 m or smaller resolution, with 100 m as maximum
- Coincident collection of thermal and short wave data for similar cloud identification and mitigation.
  - Coincident collection increases the probability of ET production by a factor of two (see Kilic et al., 2014 report to NASA Landsat 9 requirements study).

Measurements/Capabilities useful for Landsat 10+

Joel McCorkel, Kurt Thome – NASA Goddard Space Flight Center

- Atmospheric corrector
  - Low spatial resolution
  - Spectral selection specific for atmospheric decoupling
- 4-6 thermal bands
  - Enables TES
- Allow data compression
  - Loss of fidelity easily defined and can be set/prescribed to fall below accuracy/precision requirements
  - Benefit of increased information (spectral, temporal, spatial) substantially outweighs compression loss
- Maintain reference to reflectance
  - TOA reflectance is our primary data product so proving its accuracy and stability critical
  - Current method (Landsat 7, 8; MODIS; VIIRS; etc) use onboard techniques: solar diffuser and associated solar diffuser stability monitor
  - Vendor proposals must prove reflectance accuracy and stability – with or without onboard devices
  - Sufficient on-ground characterization to ensure on-orbit knowledge of sensor features
- Increase frequency of measurements
  - Don't hesitate to go back to scanning implementation
  - Distributed architecture

L10 thoughts summary: single mission continuity, higher spatial & temporal resolution, new veg. bands

Roy

Spectral

- reflective λ bands as L8 OLI - observation continuity
- add new red-edge bands - canopy chlorophyll content retrieval (MERIS, Sentinel-2 heritage) + perhaps narrow 760nm for SIF (OCO-2, GOSAT heritage)
- thermal λ bands as L8 TIRS (2 thermal bands for split-window land surface temperature retrieval) on L10 satellite OR on free-flyer satellite in same orbit ± minutes of L10 - observation continuity, reliable cloud masking and combined reflective & thermal λ applications

Spatial

- 10m / 15m reflective λ bands - better capture human activity, e.g., small holder and sub-field scale agriculture, urbanization, landscape fragmentation; and enable more meaningful integration with high resolution active (e.g., Lidar) and passive (e.g., commercial) data
- (10 / 15 × *n*)m thermal λ bands, where *n*=small integer
- sub-pixel geolocation - time series applications
- drop the panchromatic band as redundant

Radiometric

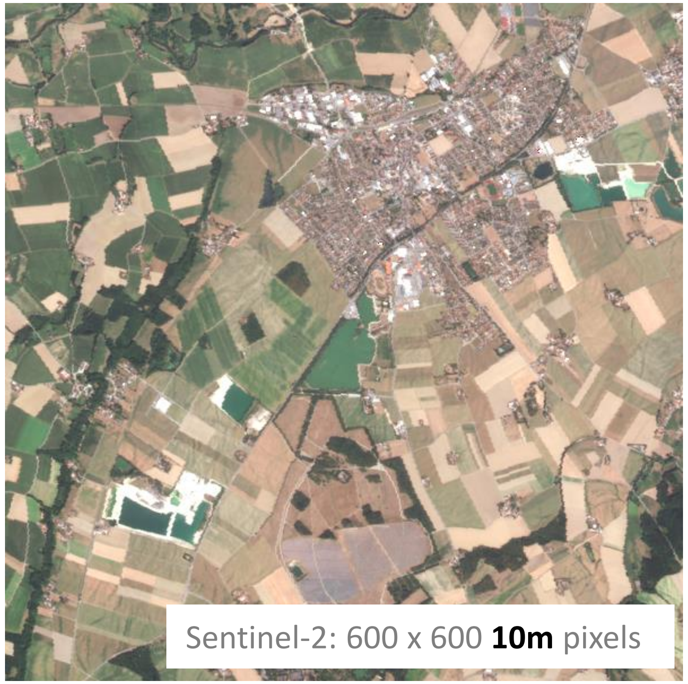
- 12 bit & SNR - observation continuity (or 13-14 bit if can make clear rationale for certain H_2O and ice applications with 10m / 15m pixels)

Temporal

- ~10 day repeat (orbit: circular, inclination >90°, diff. altitude and FOV than L8) higher than one-Landsat 16-day and closer to nominal two-Landsat 8-day repeat - change applications & improved cloud-free surface observation; - continuity of global, including polar, sun-synchronous coverage; - expectation that can integrate data with ESA Sentinel-2 & NASA VIIRS class data as needed while providing standalone Landsat mission continuity and U.S. moderate resolution reflective λ sovereignty

Field of View

- Increase FOV from 15° to 22°; trade study to consider increased repeat cycle - swath width - BRDF - image storage complexity - data rate factors



Sentinel-2: 600 x 600 **10m** pixels

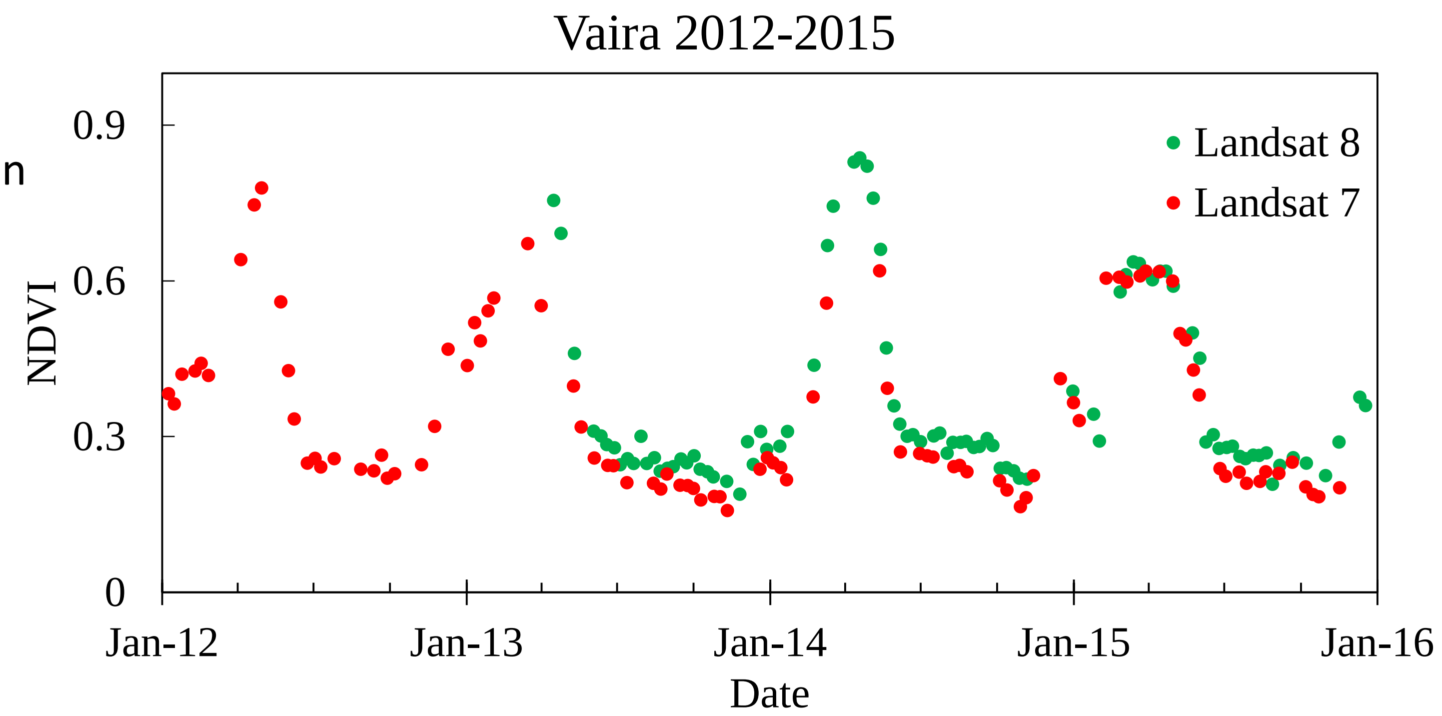
Sentinel-2: 200 x 200 resampled **30m** pixels

Schaaf

Landsat 10 and beyond

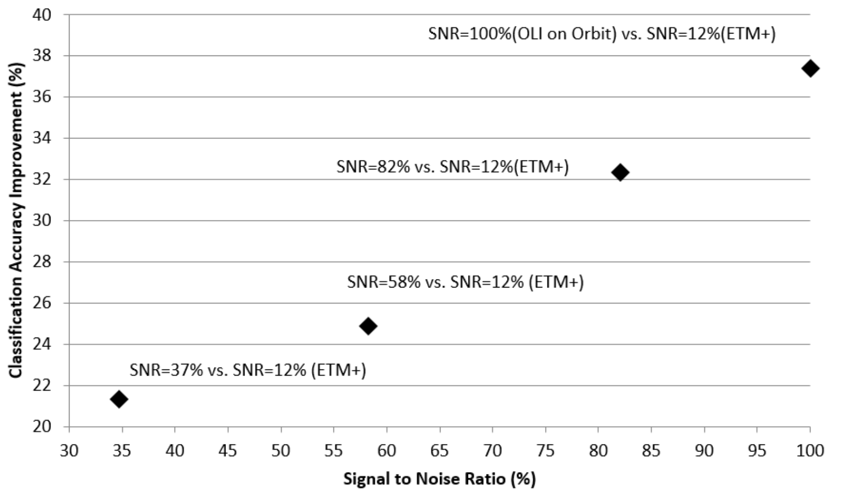
- Increased frequency of acquisitions
  - improved temporal resolution
- Sensor continuity with Landsat8
  - spectral, radiometric, spatial (same or better)
- Sensor complementary to Sentinel 2a/b sensors
- Continued access to thermal channels and cirrus channel

The Vaira flux tower site is located in a Landsat overlap region -- demonstrating the impressive time series possible (for phenological monitoring) with improved temporal acquisitions (Liu et al., 2016)

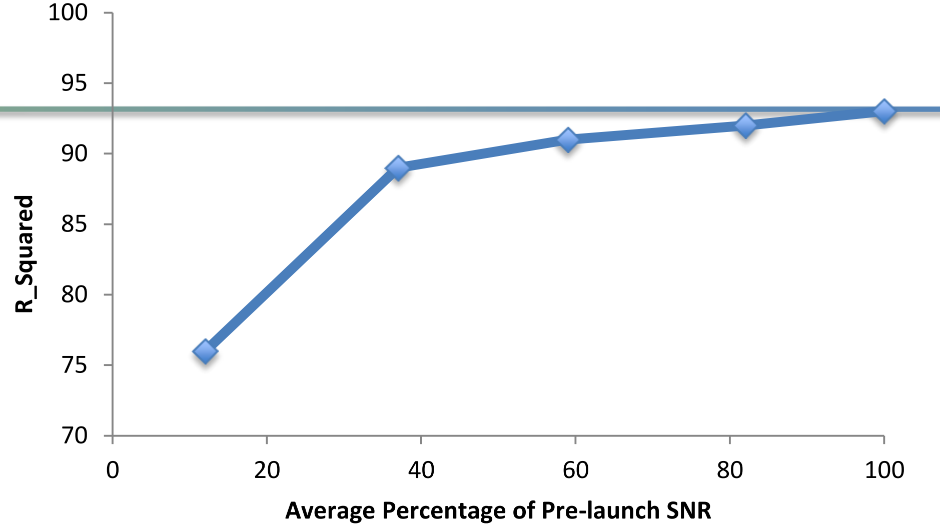


Schott

Increase SNR: Classification Accuracy Increases

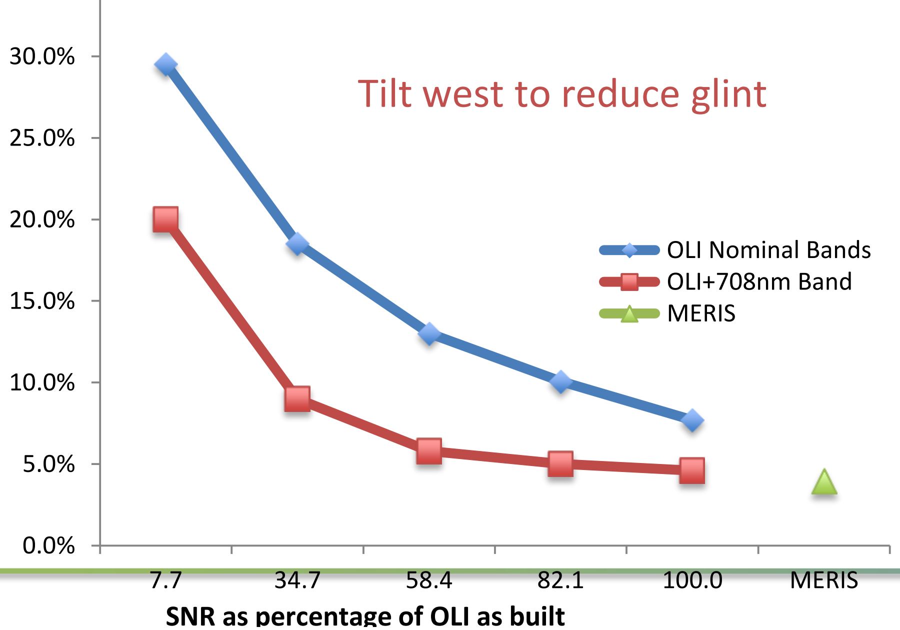


Increase SNR: Correlation of NDVI with LAI Increases



Increase SNR: Error in constituent retrieval decreases

Add a 708nm Band: Improve chlorophyll retrieval



Add additional bands: Red edge, short blue(410nm CDOM vs C), NIR(Atm. Correction over water), 620nm cyanobacteria)>>>Build an imaging spectrometer with sharpening band(s)

>>>Trade SNR, GSD and Spectral Resolution Keep Thermal- Increase Temporal

John R. Schott, Aaron Gerace, Curtis E. Woodcock, Shixiong Wang, Zhe Zhu, Randolph H. Wynne, Christine E. Blinn, The impact of improved signal-to-noise ratios on algorithm performance: Case studies for Landsat class instruments, Remote Sensing of Environment, Available online 13 May 2016, ISSN 0034-4257, http://dx.doi.org/10.1016/j.rse.2016.04.015. (http://www.sciencedirect.com/science/article/pii/S0034425716301791)

Sheng

Landsat 10 for Water

- Continuity with ancestors;
- High SNRs;
- Higher spatial resolutions of selected bands:
  - NIR, Green, Red bands in 10 m
  - Small water body mapping (0.1 ha level)
- Multispectral spectral bands for water quality.
- Thermal bands for water temperature.

Landsat 10 – Polar and ice–related perspectives

Scambos / Pope

— assuming a ~2030 launch

- 15-meter, multispectral imaging **can only be of value in this timeframe** if :
  --- radiometric resolution is exceptional (14-bit) and well calibrated
  --- acquisition frequency is very high (4 days), with **global land +sea ice coverage**
  --- Split-window thermal bands are included at 2x – 4x spatial resolution
  ---Geolocation should be <3 m globally.

- Key bands for snow and Ice are (prioritized): red, infrared, thermal, cirrus, green, swir 1.6µm;
  Keep bands and response curves as consistent as possible.

- Mission goals should emulate **MODIS** mission goals of the 2000-2010s.
  --- land ice changes, ice velocity mapping
  --- surface melting, albedo, reliable global surface reflectance product
  --- melt lakes on ice sheets, glaciers, sea ice, tundra
  --- snow cover, snow melt runoff, lake ice-on/ice-off;
  --- sea ice tracking, sea ice morphology

Landsat 10 and beyond

Vermote

- Current spectral bands and SNR specifications should be maintained
- Atmospheric correction performances could be enhanced by adding bands at shorter wavelength (deep blue 412nm)
- Work can be done on S2 to determine the usefulness of the water vapor retrieval bands (more for cloud screening)
- Polarization should be explored (as it could be added quite easily) once again in the idea of improving atmospheric correction (type of aerosol)

Landsat 10 and beyond

Vogelmann

- At the very minimum, we need Landsat sensors that do all of what L-8 can do (same specs or better)
- The science and user communities need more frequent observations. As a general rule, more is better. Routine data acquisition of medium res data every 4 days would be OK, but more frequent acquisitions would be a game changer
- Landsat 10 should be as compatible with Sentinel-2 and follow-on missions as is possible. We can build off of our current relationships between L-8 and ESA, but we should not stop there…..
- The community needs compatibility among many sources and types of spatial information and across multiple platforms: Compatibility with radar, VIIRS, MODIS, climate data, lidar, commercial sensor data, etc. We need a “system of systems” approach that could include the following:
    - Global strategy, enabling anyone from anywhere to access and analyze data from multiple sources, including satellite sensor data, climate data, DEM, soils information, etc.
    - Data processed to be compatible with other data sets as much as it makes sense (e.g., same geometric coordinates, same atmospheric calibration, etc.)
    - Processing and analysis strategy that enables users from anywhere on the globe to access and query information from anywhere on the globe (without having to import them onto their own systems).
    - Ultimate shift from imagery-driven focus to information content-driven focus:
        - Should enable detection of changes as they occur anywhere that they occur
        - Should enable better understanding of what these changes actually mean
        - Should be an international cooperative venture representing scientists from many countries

As we move forward towards L-10 and beyond, we need to facilitate development of information that can be readily used for decision making by a global body of users

Landsat 10 capabilities – Wulder*

(want continuity, ↑measurement capacity, ↓costs)

Essential capabilities

- Operational? Clones OK.
  - Continuity of "Heritage" resolution assemblage
  - New element: always-on, improved coverage from innovation to storage and transmission
- Population increase, fragmented landscapes, phenology: need more frequent, plus higher spatial and spectral resolution measures.
- What new capabilities?
  - Mate w/ Sentinel-2 (red-edge, higher spatial res., etc)
  - L10 = Heritage + S2 + TBD
    - TBD = spectral sensitivity to GHGs, aerosols, cloud, water vapour
    - Possible, but what about ↑ temporal?

Innovations

- Lower costs, increase temporal resolution?
  - Wider swath
  - More satellites 1:
    - Clones, or
    - If goal change: Gold standard + some that can be normalized to standard
  - More satellites 2:
    - If multiple satellites, not require integrated thermal?
    - "High" res thermal free flyer (+ select heritage?)
  - More partners
    - Virtual constellations
- Isolating and reducing key cost drivers
- New technology: Detectors, imaging mode (arrays, prism?)
- Novel mixed orbital modes (current polar + equatorial w/ tropics focus)

*improved by discussions with Joanne White

Landsat 10 Essential Capabilities

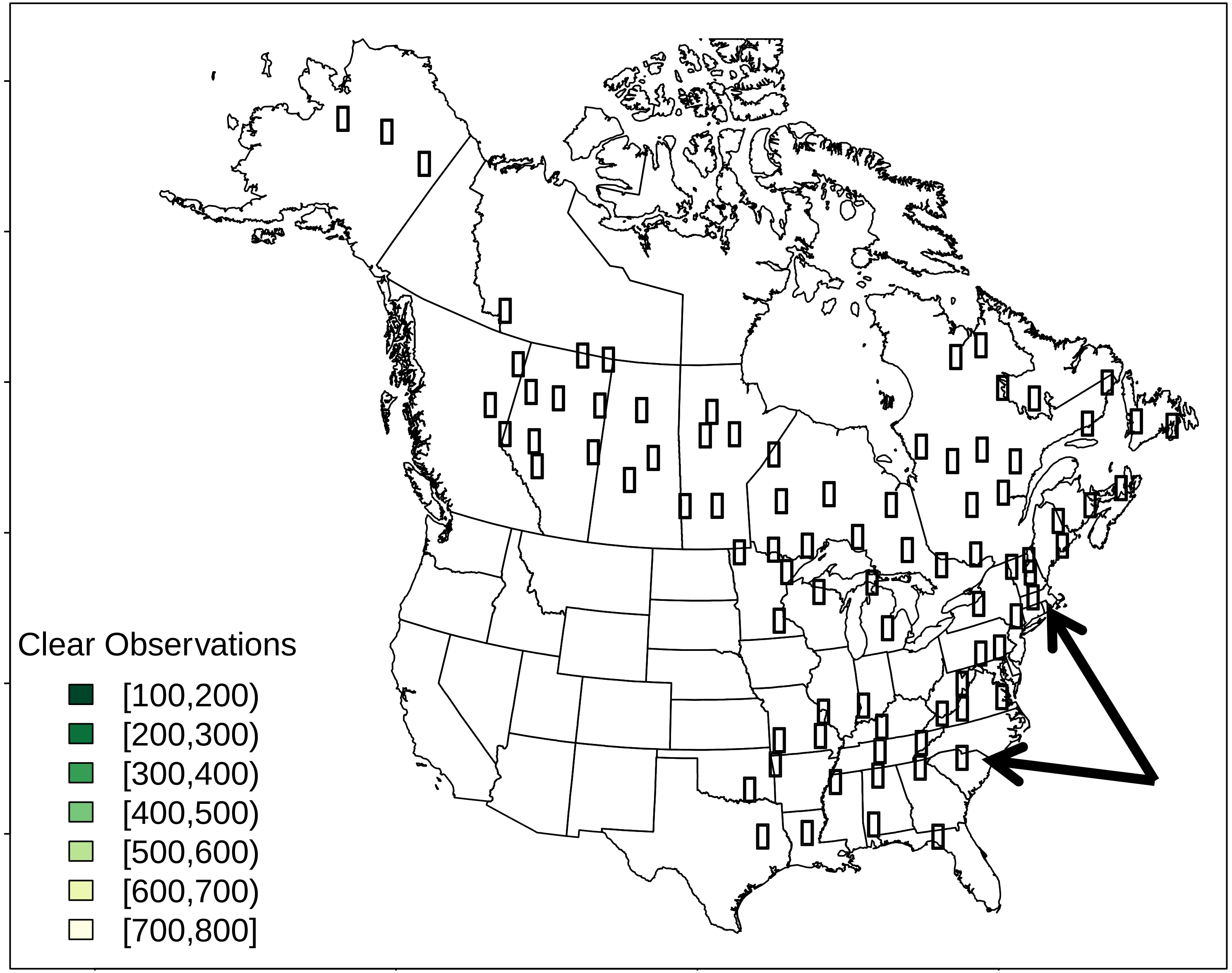
(Wynne and Thomas)

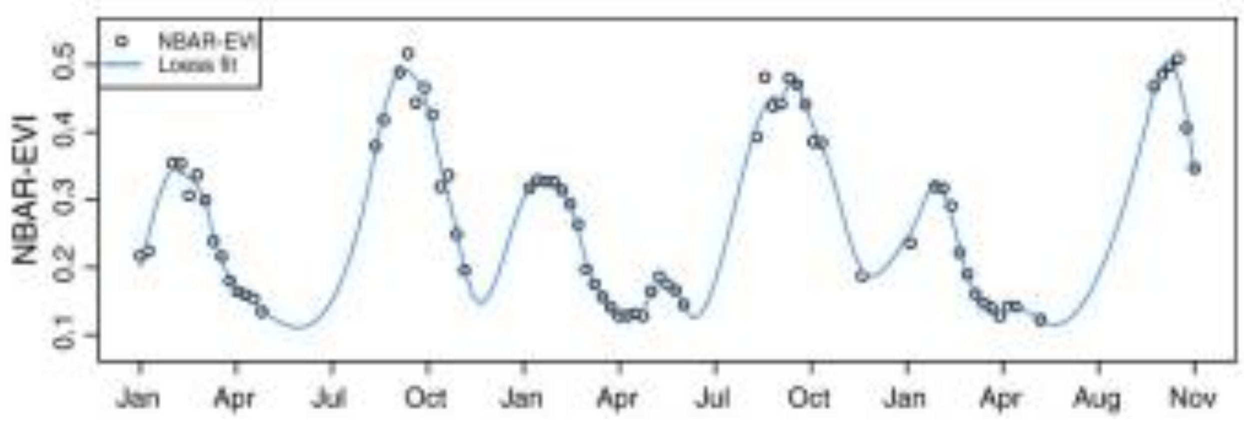
- Multispectral continuity
- Thermal
- Improved integration with Sentinel 2
- Increased resolution tradeoff order: temporal, spatial, spectral
- Explicit focus (with respect to spectral bands) on improving cloud detection and surface reflectance products
- [Simple wish list: imaging spectroscopy at least in visible and NIR]

Useful stuff from Eli Melaas and Mark Friedl on the importance of temporal frequency for monitoring forest phenology

- Look in the overlap zones of images, so you can double your observations – so with 2 Paths and 2 sensors, you essentially have 4 day data (4 observations every 16 days)
- What happens when you throw out data to your ability to estimate forest phenology?

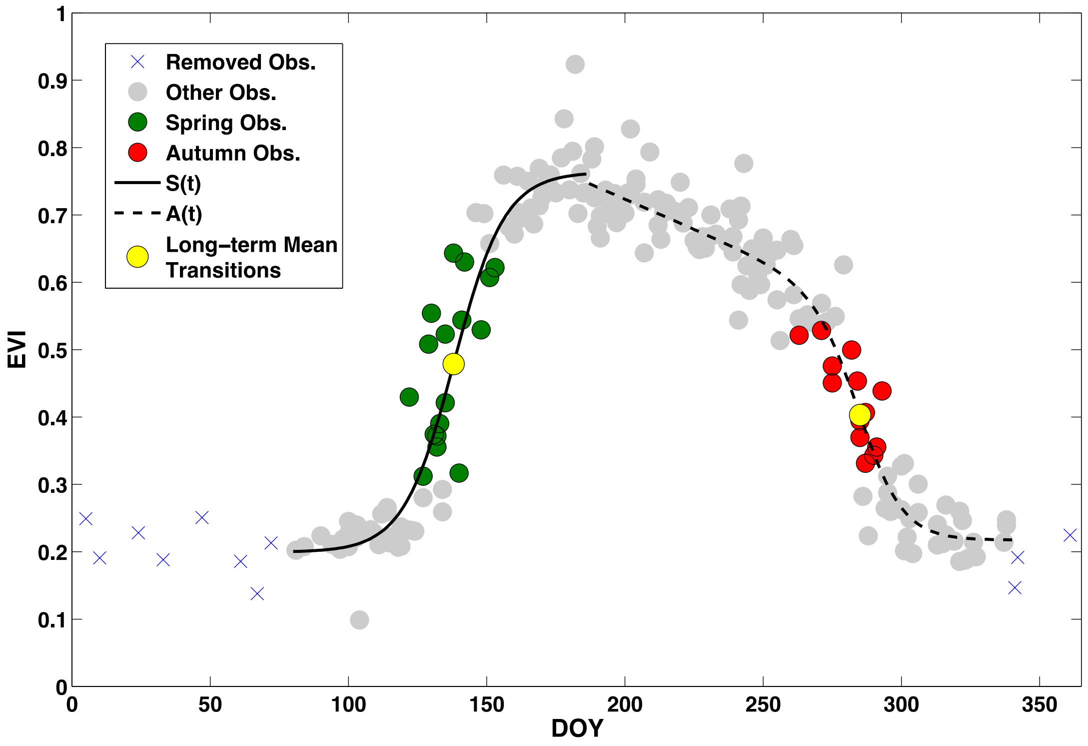
“Sidelap” regions observation availability



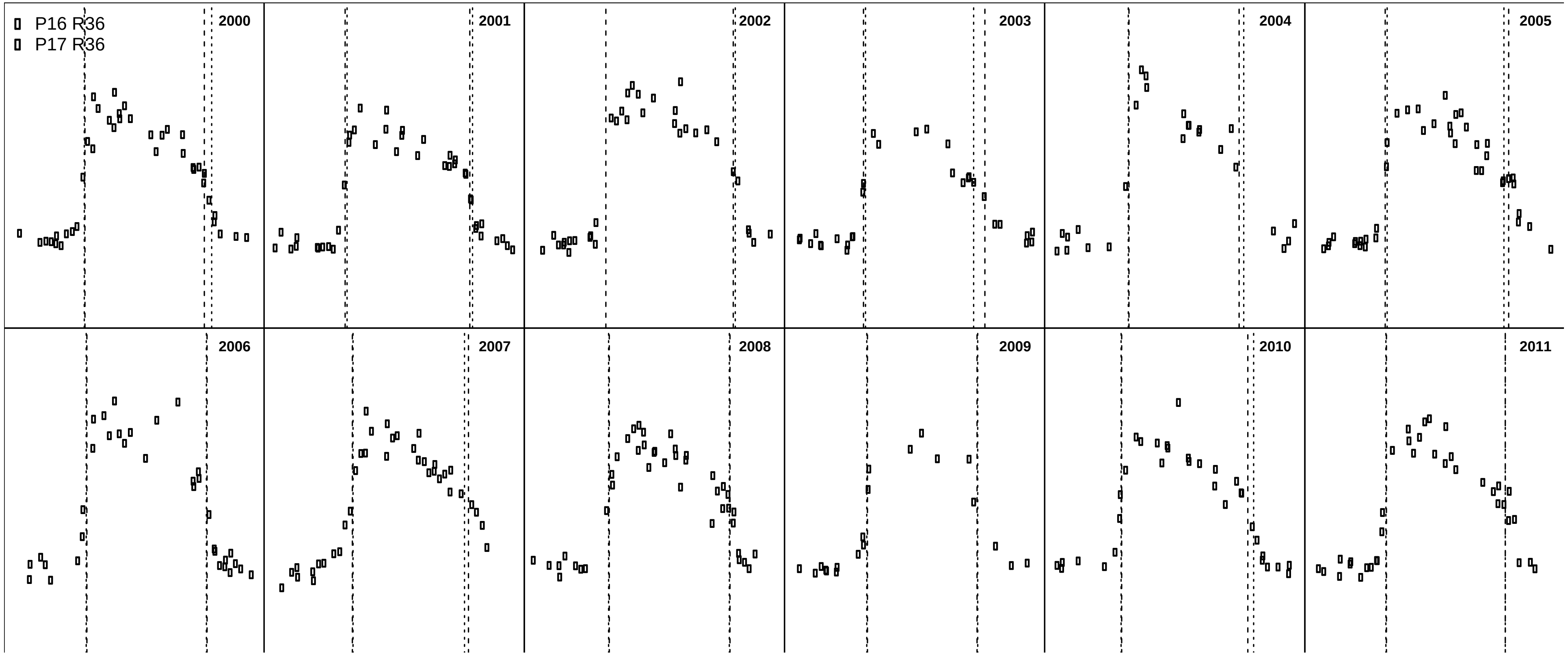


“MCD12Q2 C6”
(Gray et al. *in prep*)

“Landsat Phenology Algorithm”
(Melaas et al. 2013)



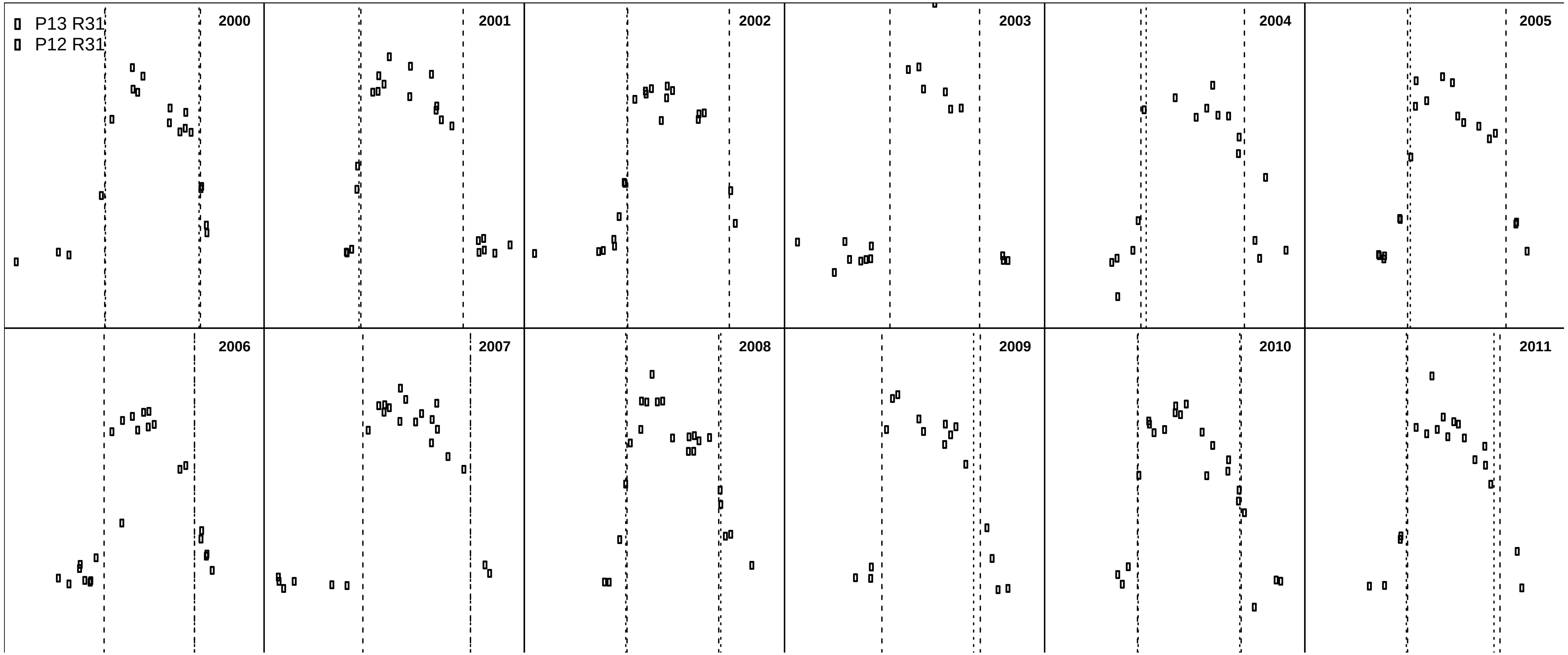
EVI time series for sample deciduous pixel: North/South Carolina (~700 obs.)



Dotted vertical lines = spring onset detection

1. MCD2Q2 ( ) and 2. Landsat Phenology ( )

EVI time series for sample deciduous pixel: Massachusetts (~400 obs.)



Dotted vertical lines = spring onset detection

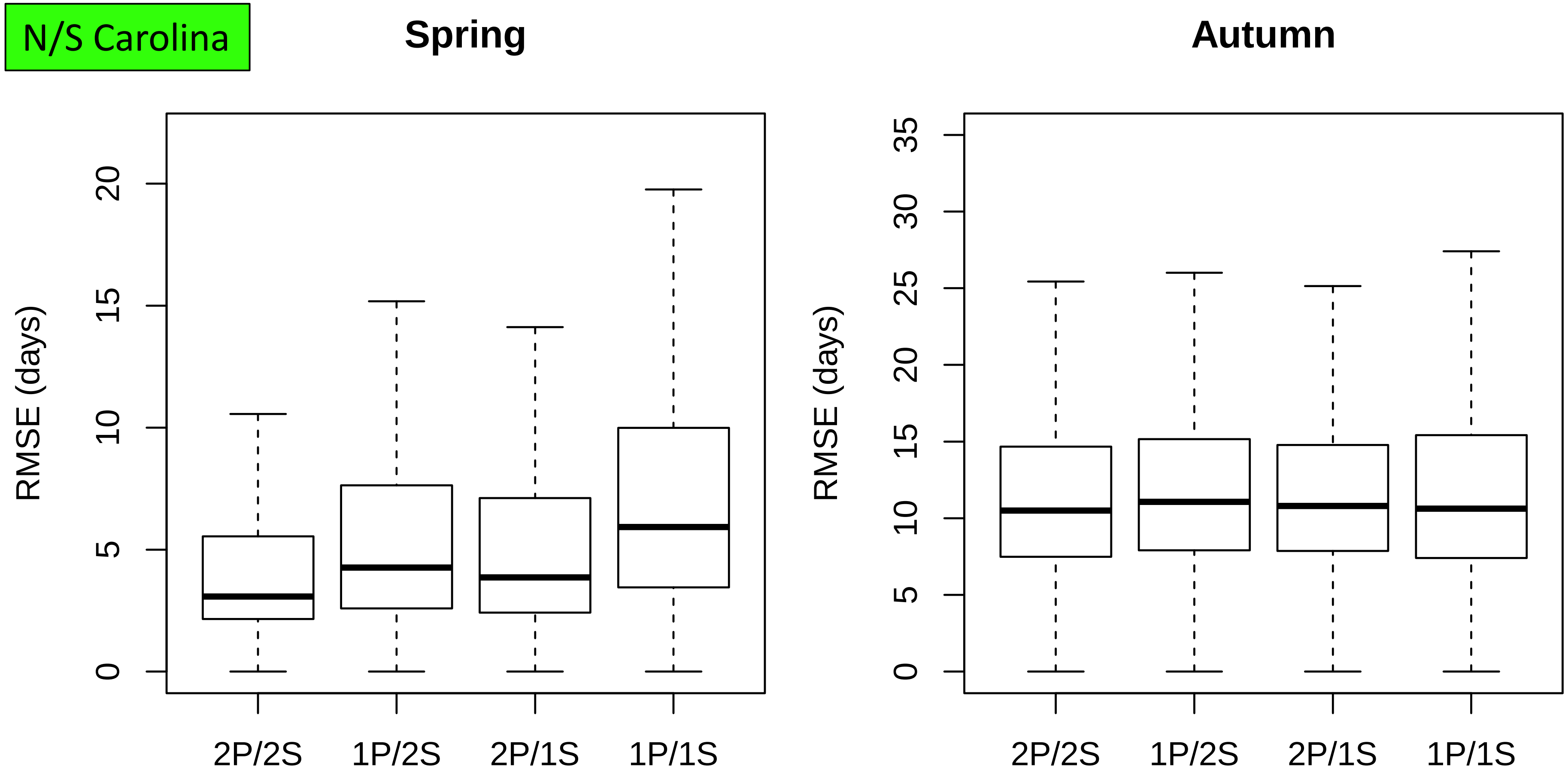
1. MCD2Q2 ( ) and 2. Landsat Phenology ( )

Compare MCD12Q2 and Landsat Phenology across 5,000 pixel sample using observations from:

1. 2 paths & 2 sensors **2.** 1 path & 2 sensors

3. 2 paths & 1 sensor **4.** 1 path & 1 sensor

N/S Carolina



Compare MCD12Q2 and Landsat Phenology across 5,000 pixel sample using observations from:

1. 2 paths & 2 sensors **2.** 1 path & 2 sensors

3. 2 paths & 1 sensor **4.** 1 path & 1 sensor

Massachusetts